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A Direction Finding System for Transient Signals

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Abstract: Currently deployed direction finders used with radio-tagged animals have proved to be of great value in the study of endangered species of wildlife. The automated collection of directional data, supplanting or supplementing individual researchers with hand-held instruments, has permitted major increases in research productivity. However, only one design of a suitable automated instrument exists on the market, available from only one source, in limited quantities, and still in a developmental stage. The current users of this equipment experience much difficulty in achieving the results for which they originally hoped. We believe this equipment can eventually be improved in performance and reliability, but it will take much time and effort on the part of the researchers who use it in the field. It is possible to develop a much more capable instrument, based on more modern technical concepts. The resulting instrument should have higher accuracy and reliability, would employ a greatly simplified antenna system and thus be more portable, and, using mainly off-the-shelf components and widely used software, should be more reliable.

Preface

This technology is under development with funding from the program for "Threatened and Endangered Species," for which Dr. Timothy Hayden is the Program Manager, and Dr. William Severinghaus is the Technical Director. The document contained in this special report was submitted to the Army Science Conference 2004 and approved as a summary paper.

The work was performed by the Ecological Processes Branch (CN-N) of the Installations Division (CN), Construction Engineering Research Laboratory (CERL). The CERL Principal Investigator was George W. Swenson. Todd Borrowman (CERL) is acknowledged for his preparation of the figures and calculations contained in the paper. Alan Anderson is Chief, CN-N, and Dr. John T. Bandy is Chief, CN. The Deputy Director of CERL is Dr. Kirankumar V. Topudurti, and the Director is Dr. Ilker R. Adiguzel.

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A DIRECTION FINDING SYSTEM FOR TRANSIENT SIGNALS

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INTRODUCTION

Currently deployed direction finders used with radio-tagged animals have proved to be of great value in the study of endangered species of wildlife. The automated collection of directional data, supplanting or supplementing individual researchers with hand-held instruments, has permitted major increases in research productivity. However, there exists on the market only one design of a suitable automated instrument, available only from a single source in limited quantities, and still in a developmental stage. The current users of this equipment experience much difficulty in achieving the results they originally hoped for. We believe this equipment can eventually be improved in performance and reliability, but it will take much time and effort on the part of the researchers who use it in the field. It is possible to develop a much more capable instrument, based on more modern technical concepts. The resulting instrument should have higher accuracy and reliability, would employ a greatly simplified antenna system and thus be more portable, and, utilizing mainly off-the-shelf components and widely used software, should be more reliable.

1 BACKGROUND

The existing automatic signal recording and direction-finding system has been deployed in Southern California and in Panama but has not yet demonstrated the ability to supply reliable and precise directional data. Assuming that it can eventually do so, it is inevitable that many more of these devices will be required by the wildlife ecology community.

The automatic recording units are available from only one source and in small quantities. It is important that the supply be increased and it is appropriate to consider at this point whether significant improvements can be made in their sensitivity, reliability, speed, precision, and economy. The design principles of the current system probably preclude any substantial improvement except in reliability, which will no doubt improve as using agencies accumulate more experience. Speed of operation has become a serious issue. The automatic recording unit contains only one radio receiver, which must be connected sequentially with each directional antenna, of which there are six in the current configuration.

2 PROPOSED SYSTEM

A signal voltage delivered to a radio receiver from an antenna consists of two parts, the amplitude and the phase, or, alternatively, the real and the imaginary parts of a complex analytic signal.

The traditional approach to direction finding is to use only one of these components, either phase or amplitude. We propose to use both parts, thereby doubling the number of data derived from the signal. This technique is now used nearly universally in radio astronomy, for example, and in several other branches of the array signal processing profession. This system requires six seconds to make a single observation of signal strength and direction. Then, if there are more

animals to be observed the frequency is changed (automatically) and the cycle repeated, and so on. The rate of data acquisition is slow if many animals are to be monitored, and especially slow if redundant measurements are made to increase precision of azimuth determination.

In considering the speed problem obviously one way to improve matters is to provide a separate receiver for each antenna to obviate the sequential switching of antennas and receiver. That leads one to consider the direction-finding principle itself. The current system is a special adaptation of the classical Watson-Watt direction finder, which derives directional information by comparing the amplitudes of the signals received (from the same source) on two different antennas. The alternative principle, which is commonly used in narrow aperture direction finders, is the phase comparison scheme, sometimes called interferometry, which, as the name implies, compares the phases of the signals received by two pairs of antennas. The latter principle includes as a special case the so-called pseudo-Doppler system. Though there are many direction finders on the market using each of these principles, none of them use all of the directional information available in the radio signal.

No application to small aperture direction finding appears to have been attempted. Utilizing the complex signal requires a different type of radio receiver, incorporating a complex detector to deliver the two components of the signal. The current receivers do not do this. Having two components of each sample of the received signal inherently increases the sensitivity of the receiver and improves its performance in the presence of random noise. This is a relatively simple change in the receiver design from the current model.

Changing the receiver design gives an opportunity to incorporate additional advances in the art. A new concept in receiver design called the "software defined receiver" is being developed, which permits the simultaneous reception of many signals on different frequencies, yields both components of each complex signal, and separates, identifies and, if desired, supresses interfering signals. This receiver concept involves fewer electronic hardware components than traditional receivers, substituting digital signal processing procedures in an associated computer or microprocessor.

The antenna system of the proposed direction finder involves many fewer components and is much more compact and light weight than the currently deployed system. This promises lower cost and greater ruggedness, portability and maintainability.

A collateral benefit of this project would be development of an acoustical direction finder. The same principles apply to sound waves as to radio waves; only the sensors utilize different physical principles. Existing microphones can be equipped with appropriate baffles to yield the requisite directional properties. The existing sound amplifiers, signal processing software and data storage facilities can be used. The direction finding algorithms developed for the radio direction finder can be used for the acoustical case. Studies of sound propagation would benefit from the ability to detect the direction of arrival of a sound wave at an observation point, given the strong influences of atmospheric refraction and multipath propagation.

The goal is to measure the direction to a source of a single, short, signal pulse. The system consists of an assembly of several co-located sensors, each having the same reception pattern in the horizontal plane, except for individual azimuth index angles (Fig. 1). The reception pattern must have significant asymmetries.

The reception patterns of all sensors are identical and as they are well known and are indexed at nonduplicated azimuths, simultaneous reception of a signal by all sensors is equivalent to sampling the common reception pattern at a number of different azimuths. Simultaneous reception of a signal by all sensors is equivalent to sampling the common reception pattern at a number of different azimuths. The azimuth of the target is determined by fitting complex amplitudes measured by the sensors to the known pattern transfer function, minimizing the error by varying the azimuth of the index. The precision of target azimuth determination improves with greater signal to noise ratio.

This principle can be employed for direction finding of either sound or radio waves. For sound waves the sensors would be microphones with baffles de-

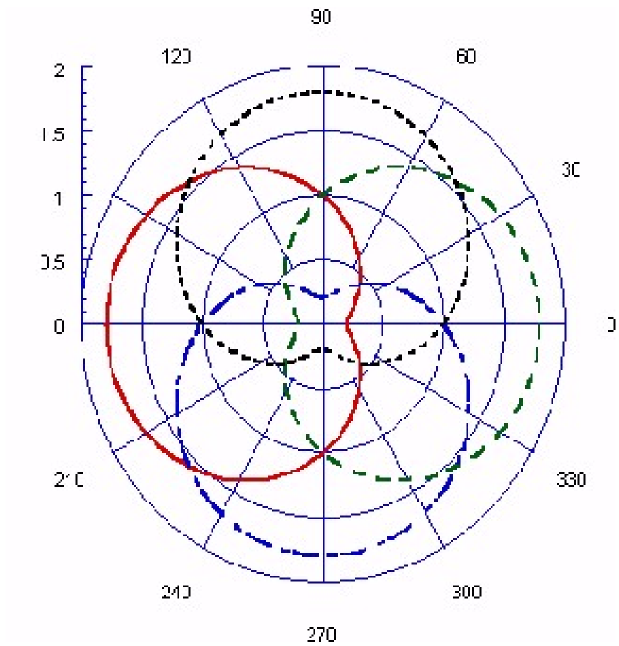

Figure 1: Image graphed according to the amplitude of an isotropic sensor.

signed to give appropriate directional patterns. The signal processing technique can work on short segments of the signal, so that varying azimuths can be followed. For radio waves this technique requires a separate receiver for each sensor (antenna). These receivers must be identical (or able to be calibrated) in gain, bandwidth, band shape and phase. A single local oscillator is used for all receivers. It should be possible to manufacture arrays of identical receivers at low cost using off-the-shelf receiver chips. Much of the receiver function can be accomplished in software. It has been shown by modeling that a suitable, simple, antenna array can be designed involving only a single dipole for each receiver.

Figure 2 shows how utilizing both phase and amplitude in the azimuth determination improves the precision relative to using either parameter alone; the radial scale is the standard deviation of the azimuth in degrees.

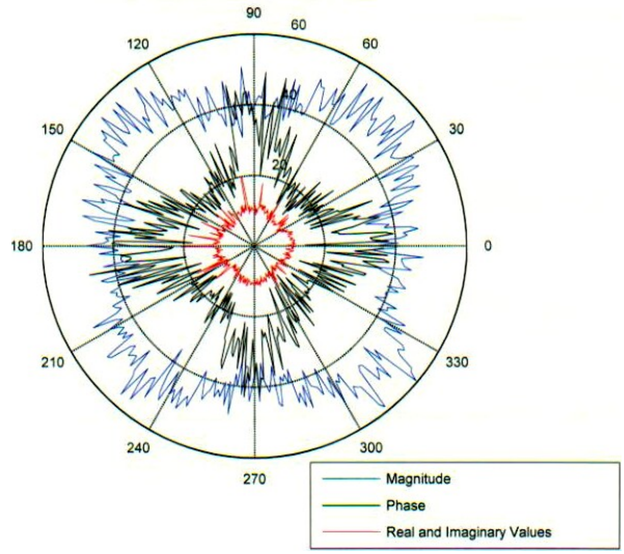

Figure 2: Error graphed as the standard deviation of azimuth in degrees.

3 CONCLUSION

With the current state of development of digital signal processing techniques it is now possible to deploy electromagnetic and acoustical direction finders capable of enhanced abilities in the detection of transient signals and determining their directions of arrival.

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14. ABSTRACT

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